PSC STAFF REPORT: WISCONSIN'S STRAY VOLTAGE EXPERIENCE – AN UPDATE

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INTRODUCTION

The Wisconsin Stray Voltage Analysis Team (SVAT) is jointly administered by the Public Service Commission of Wisconsin (PSCW) and the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP). The SVAT consists of an electrical engineer, a master electrician and a veterinarian. The SVAT has been collecting data from on-farm stray voltage investigations since being established in 1989. The major investor-owned utilities (IOUs) in Wisconsin have also recorded information from their stray voltage investigations at the request of the PSCW since 1988. The data is submitted to the PSCW every six months and is entered into a utility database. This data has been documented in an earlier publication. This paper is intended to update the picture from data collected since that publication.

The SVAT data includes information from applications for on-farm investigations, and actual on-site investigations. Not all applications result in a full investigation, therefore some entries contain only the data sent by the applicant, or information from a partial investigation. To date, 346 applications have been received by the SVAT of which 222 or 64 percent have resulted in some form of investigation. This represents farms that receive their power from 147 (43 percent) cooperatives (coops), 174 (50 percent) IOUs and 25 (7 percent) municipal (muni) utilities.

Data from Wisconsin's five largest IOUs, gathered over the same period of time during their first-time farm investigations, is submitted semiannually to form a separate utility database. The IOU farm-customer representatives are usually trained stray voltage specialists at the technician or engineer level. Therefore, the PSCW has a high degree of confidence in the accuracy and veracity of the data. There are more than 2,900 first-time farm investigations reported between mid-1993 and early 1998 in the utility database, representing about 12 percent of all Wisconsin dairy farms.

The form of the data collected by the utilities was standardized beginning in 1993 to correspond with the data collected by the SVAT. While each database is similar since 1993, the SVAT database includes data from municipal and cooperative electric power companies as well as from the IOU's. Unique to the SVAT portion of the database is information about the primary power delivery system, and specific concerns of the applicant. For each utility investigation, data is recorded about the characteristics of the distribution system serving the farm including:

1. Primary phase voltage,
2. Material and size of the phase and neutral conductors,
3. Number of ground rods per mile near the farm,
4. kVA rating of the primary transformer,
5. Circuit miles from the farm to the nearest distribution substation, and
6. Location relative to the end of a branch line.

Characteristics of the farm include:

1. Herd size in number of milking cows,
2. Type of herd data recording system (e.g. DHIA or other),
3. Average milk production and Somatic Cell Count from the most recent test information,
4. Type of milking facility, and
5. Type of stray voltage mitigation devices installed (as found) and recommended.

Electrical measurements on the farm include:

1. The maximum steady state value of the cow contact current found at the worst-case cow contact location (The cow contact current is measured as the current flowing through a 500 ohm shunt resistor connected across cow contact points),
2. The source resistance of the cow contact measurement point,
3. Maximum steady state value of the primary neutral to earth voltage, and
4. Maximum steady state value of the secondary neutral to earth voltage.

Additional data collected by the SVAT includes:

1. Data from a profile of the distribution system near the farm reporting ground rod current, ground rod resistance, and primary neutral to earth voltages,
2. Major herd health and production concerns of the applicant, and
3. Farm professionals and others the applicant had previously contacted.

The reader should note that this is not a random sample of Wisconsin farms. Investigations done by the utilities were usually done at the request of farm customers. The investigations conducted by the SVAT were accomplished only after a utility investigation had been performed and the farm customer was still concerned about possible stray voltage.

The PSCW reviewed its stray voltage rules in 1997. The PSCW has defined as a standardized measurement of stray voltage, the voltage measured across a 500-ohm (nominal) resistance connected between two animal contact points. The “level of concern” has recently (per PSCW Docket 05-EI-115) been defined as 1.0 volt, AC 60 Hz. rms of animal contact voltage measured in this manner (or 2.0 milliamps, AC 60 Hz, rms of animal contact current). The standard does not refer to any human contact with voltages and currents nor to any harmonic content, which may or may not be present in addition to the fundamental frequency. Other electrical phenomena that are not included in any PSCW orders are medium frequency transients

(>3 kHz) and radio frequency (RF)-source transients (>500 kHz) induced from sources outside the distribution power system including currents in the earth. The new “level of concern” is a combined contribution from both on-farm and off-farm sources. The utility contribution may be no more than 1/2 of this total. The PSCW believes the “level of concern” for confined animals is a conservative, preventive level, below the point where moderate avoidance behavior is likely to occur and well below where a cow's behavior or milk production would be harmed. An animal contact measurement location has been defined as any area where an animal could simultaneously contact two conducting surfaces having a difference in electrical potential. The test methods used to measure animal contact voltages as well as primary and secondary neutral voltages have been well defined by the PSCW. Utility investigators have been made aware of these standardized procedures through various educational efforts conducted by the SVAT and the University of Wisconsin beginning in 1989.

UPDATING THE WISCONSIN EXPERIENCE

Distributions of the major electrical and dairy performance measurements are presented in Figures 1-11. The median values reported by the SVAT and IOU investigators are as follows:

PARAMETER	Median (SVAT)	Median (IOU)
Distance to substation miles	5.0	5.0
Grounds per Mile	10	10
Primary Neutral to Earth Voltage	1.10	0.90
Secondary Neutral to Earth Voltage	1.07	0.95
Cow Contact Voltage	0.30	0.24
Herd Size	53	52
Average Production (RHA)	17,000	18,000
Somatic Cell Count	421,000	300,000

As one can see, the two databases agree well for the parameters shown. More than 90 percent of farms served by IOUs are within 10 circuit miles of a substation. More than 95 percent of farms have distribution systems that exceed the minimum number of grounds per mile required for IOU’s in Wisconsin. The difference between the SVAT and utility databases is that the SVAT data contains investigations from Rural Electric Cooperatives and municipally owned utilities as well as IOUs. The predominant distribution voltage is 7,200 volts with only 3 farms served by a 2,400-volt distribution system and about 20 percent served by a 14,400-volt distribution system. The predominant transformer size reported is 25 kVA. More than 85 percent of the first investigations reported maximum primary and secondary neutral voltages less than 2 volts rms. More than 90 percent of investigations reported maximum cow contact voltages less than 1.0 volt rms.

A summary of the current flowing to ground on primary ground rods from 175 SVAT investigations is shown in Figure 8. This data consists of readings of current taken from all distribution line ground rods for a distance of 1.5 miles centered about the farm being investigated. The mean and median values of current are 41 and 19 milliamps respectively. The mean and median primary ground resistance was 78 and 32 ohms. This compares with a study conducted by other researchers in which the mean resistance was reported as 119 ohms for 42 readings.

The correlation coefficient was calculated between all variables in the IOU database for more that 2,900 investigations performed from 1993 to 1997. A weak correlation was found between primary neutral and secondary neutral to earth voltages (r = 0.65), transformer size and herd size (r = 0.52), secondary neutral and cow contact voltage (r = 0.51), primary neutral and cow contact voltage (r = 0.39), herd size and milk production (r = 0.27), and milk production and somatic cell count (r = -0.23). There was no meaningful correlation between any of the electrical parameters and milk production or somatic cell counts (r < 0.07). These distributions and correlations are comparable to data previously reported in a SVAT paper.

The correlations between electrical parameters are as expected from electrical theory. However, as indicated in a previous staff paper from 1995, specific measurement of each parameter is required because the predictive ability is very low. Gross indicators such as grounds per mile, primary or secondary neutral to earth voltages are not good predictors of cow contact voltage. This is probably due to the prevalence of on-farm sources, which can either add or subtract from primary sources. It is thus imperative to properly identify the voltage sources and their interaction before recommending a mitigative action. That previous report concluded no meaningful correlation between cow contact voltage and either milk production or somatic cell count. The greater number of data points in the current database produced similar results. The monthly average somatic cell count recorded by utility investigators was compared with data recorded by the USDA for the federal order regions 68 (Upper Midwest) and 30 (Chicago). These data are presented in Figure 12. The seasonal nature of somatic cell count is apparent, with the yearly maximum occurring during the summer months. The correlation between the IOU reported SCC counts and the monthly average SCC reported by USDA was r = 0.59 for region 68 and r = 0.58 for region 30. This correlation is an order of magnitude higher than for any electrical parameter.

STRAY VOLTAGE MITIGATION AND WIRING METHODS

Some common stray voltage mitigation methods reported from over 2,900 farm investigations done by utility investigators from 1993 to 1997 are summarized below. The mitigation and wiring methods found at the time of the first investigation done on that farm by a utility investigator were reported as follows:

As-found On-farm Mitigation and Wiring Methods	% of Farms
Equipotential Plane	**12.4**
4-Wire System	**6.9**
Isolation Device	**0.4**
Active Voltage Suppression Device	**0.4**

An equipotential plane was reported on about 12 percent of farms. A 4-wire system was found on about 7 percent of farms. A 4-wire system has been required for separating ground and neutral interconnections in branch circuits in Wisconsin since the early 1960's. Other mitigation methods were found on less than 1 percent of farms.

The on-farm mitigation methods or improvements to the farm wiring system recommended by the utility investigator after the investigation was completed were reported as follows:

On-Farm Mitigation Recommended by Utility Investigator	% of Farms
Improve Grounding	26.7
Increase size of Secondary Neutral Conductor	22.6
Balance 120 V loads	15.2
Install 4-Wire System	7.0
Install Equipotential Plane	3.8
Install Active Voltage Suppression Device	0.3
Install On-Farm Isolation Device	0.2

The most common mitigation methods recommended by utility investigators were improved grounding (27 percent), increased size of secondary neutral conductor (23 percent), and balancing 120 V loads (15 percent). A 4-wire system was recommended on 7 percent of farms and an equipotential plane on 4 percent of farms. Other mitigation methods were recommended on less than 1 percent of farms.

The off-farm mitigation methods implemented by the utility were reported as follows:

Off-Farm Mitigation Methods Implemented	% of Farms
Improve Grounding	16.1
Increase Size of Primary Neutral Conductor	13.9
Install Neutral Isolator	7.2
Rebuild Distribution Line	4.4
Install Underground Primary Conductor	1.6
Balance Primary Loads	1.0

The most common off-farm mitigation methods implemented by utilities were improving grounding of the distribution system (16 percent), and increasing the size of the primary neutral conductor (14 percent). Neutral isolators were installed on 7 percent of farms; the distribution line was rebuilt on 4 percent of farms, underground service conductors installed on 2 percent of farms and primary load balancing was used on 1 percent of farms.

The on-farm and off-farm mitigation methods that had been implemented by the applicants to SVAT were reported as follows:

Methods Implemented	# of Responses	% reporting this feature
Add Grounding	211	77
Rewire Barn	186	62
Add Bonding	181	43
Add Isolation Device	163	41
Add Equipotential Plane	163	30
Change Work Routines	151	27
Add Active Voltage Suppression Device	150	17

Note that the applicants to the SVAT had already had one or more stray voltage investigations performed by the utility or other investigator and many had implemented mitigation methods.

The most common methods reported are improving grounding (77 percent), rewiring the barn (62% percent, adding bonding (43 percent), installing an isolation device (41 percent), and installing an equipotential plane (30 percent).

Applicants to the SVAT reported that they had previously contacted the following types of individuals in regard to their stray voltage concern:

Contact	Responses	% reporting this feature
Utility	252	96
Veterinarian	213	84
Electrician	225	80
Equipment Dealer	214	73
Feed Dealer	189	59
Consultant	188	59
Phone Company	173	35

The main concerns indicated by applicants to the SVAT were as follows:

Concern	Responses	% reporting this feature
Increased SCC	284	87
Reduced Milk Production	279	78
Foot/Leg Problems	284	77
Uneven Milkout	285	76
Nervous Cows	284	75
Increased Mastitis	284	72
Poor Milk Let Down	285	70
Small/Weak Calves	284	52
Reduced Water Intake	285	50
Reduced Feed Intake	285	46
Other	283	26

SUMMARY

Data from more than 2,900 stray voltage investigations performed in Wisconsin by Investor Owned Utilities (IOU) and the Stray Voltage Analysis Team (SVAT) are reported. Data includes electrical characteristics of both the distribution system and on-farm wiring system as well as milk production and somatic cell counts. More than 85 percent of the first investigations reported maximum primary and secondary neutral-to-earth voltages less than 2 volts AC, 60 Hz, rms. More than 90 percent of the investigations reported maximum cow contact voltages of less than 1 volt AC, 60 Hz, rms. The distribution of variables measured by the SVAT and IOU investigators compared well, indicating that consistent testing methods are being used.

There are many confounding factors that outweigh the possible effect of measured stray voltage on farms. There was no meaningful correlation between any of the electrical parameters and milk production or Somatic Cell Counts (SCC) ($r < 0.07$). The correlation between the

monthly average SCC in the database and the monthly average SCC reported by USDA for all farms in the mid-west was an order of magnitude higher than for any electrical parameter. No other effects from electrical exposure were considered in this report.

The correlation found among the various electrical parameters are as expected from electrical theory. However, specific measurement of each parameter is required because predictive ability is low. Indicators such as grounds per mile, primary neutral-to-earth voltages or secondary neutral-to-earth voltages are not good predictors of cow contact voltages. This is probably due to the prevalence of on-farm voltage sources, which can either add or subtract from primary voltage sources. It is thus imperative to properly identify the voltage sources and their interactions before purchasing and implementing mitigative actions.

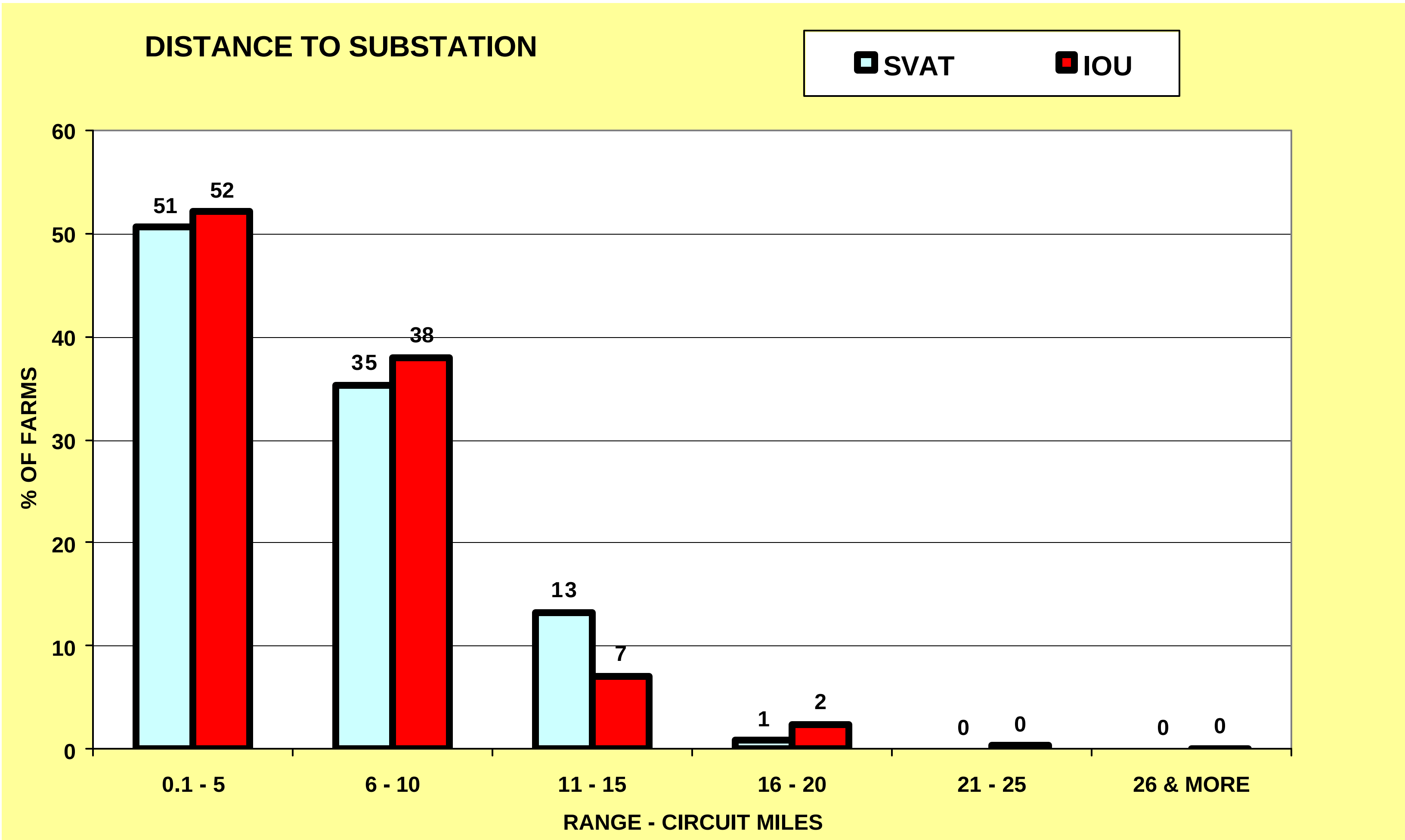

DISTANCE TO SUBSTATION
SVAT
IOU
% OF FARMS
60
50
40
30
20
10
0
51
52
35
38
13
7
1
2
0
0
0
0
0.1 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 & MORE
RANGE - CIRCUIT MILES

FIGURE 1

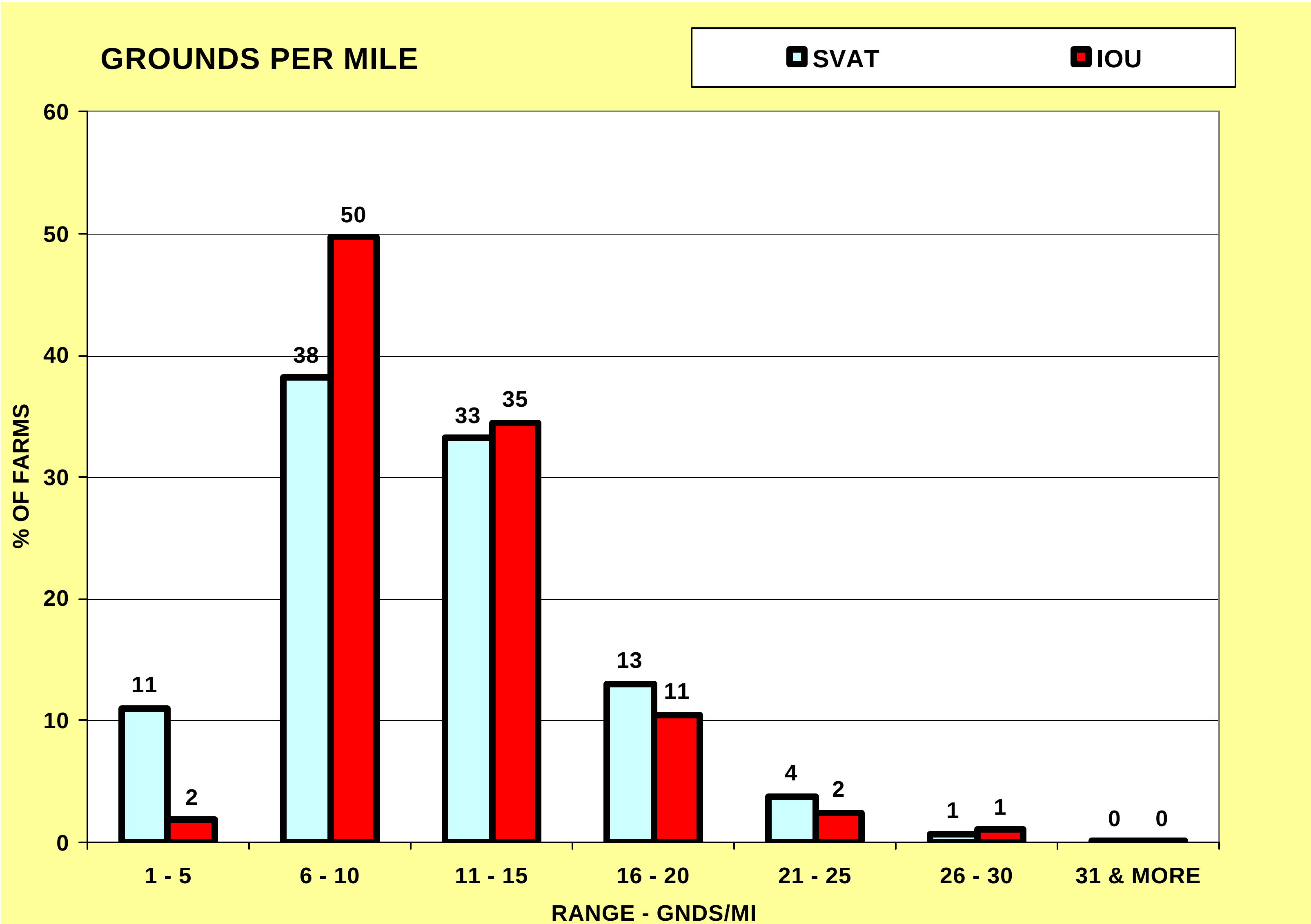

GROUNDS PER MILE
SVAT
IOU
% OF FARMS
60
50
40
30
20
10
0
11
2
38
50
33
35
13
11
4
2
1
1
0
0
1 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 30
31 & MORE
RANGE - GNDS/MI

FIGURE 2

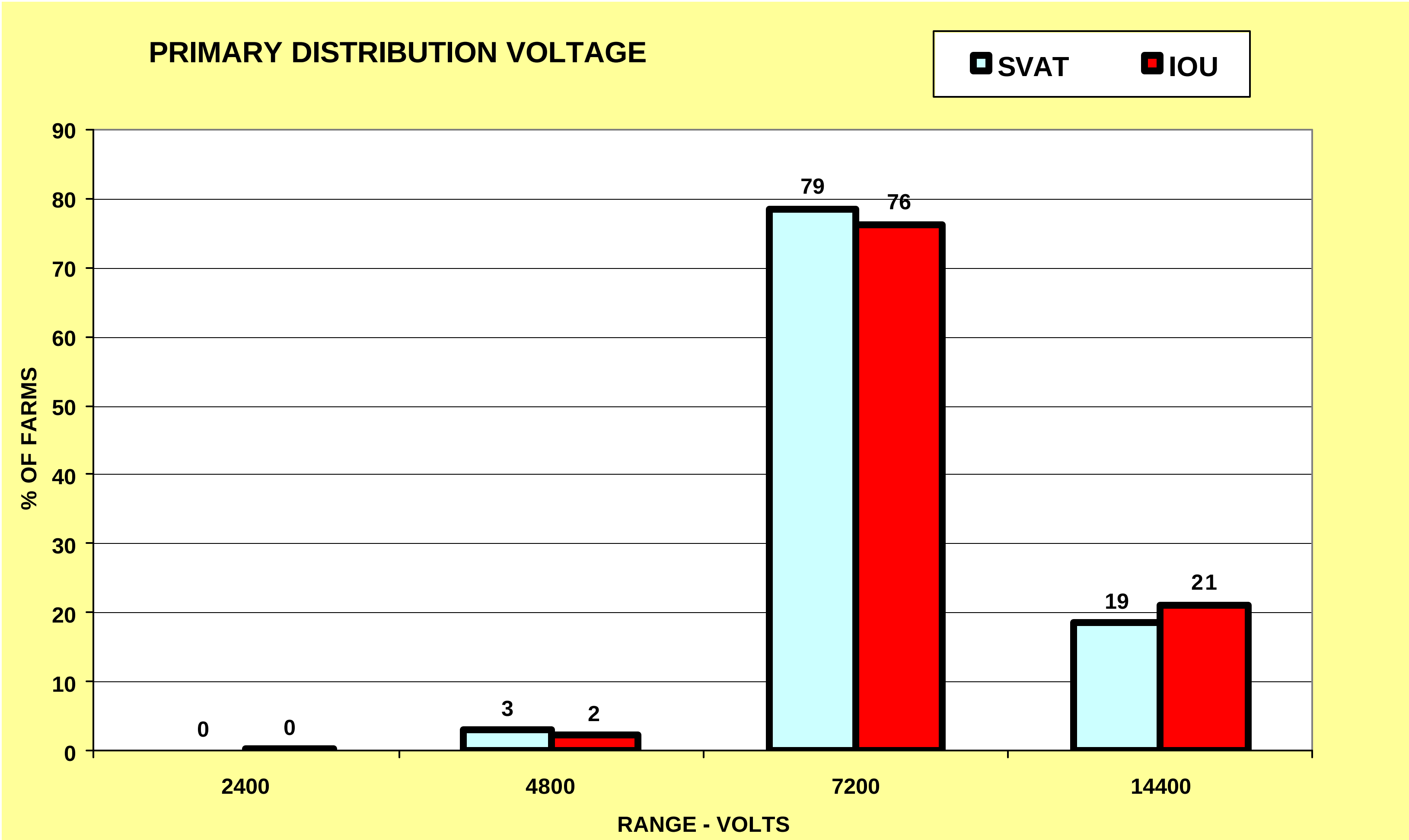

PRIMARY DISTRIBUTION VOLTAGE
SVAT
IOU
90
80
70
60
50
40
30
20
10
0
% OF FARMS
0
0
3
2
79
76
19
21
2400
4800
7200
14400
RANGE - VOLTS

FIGURE 3

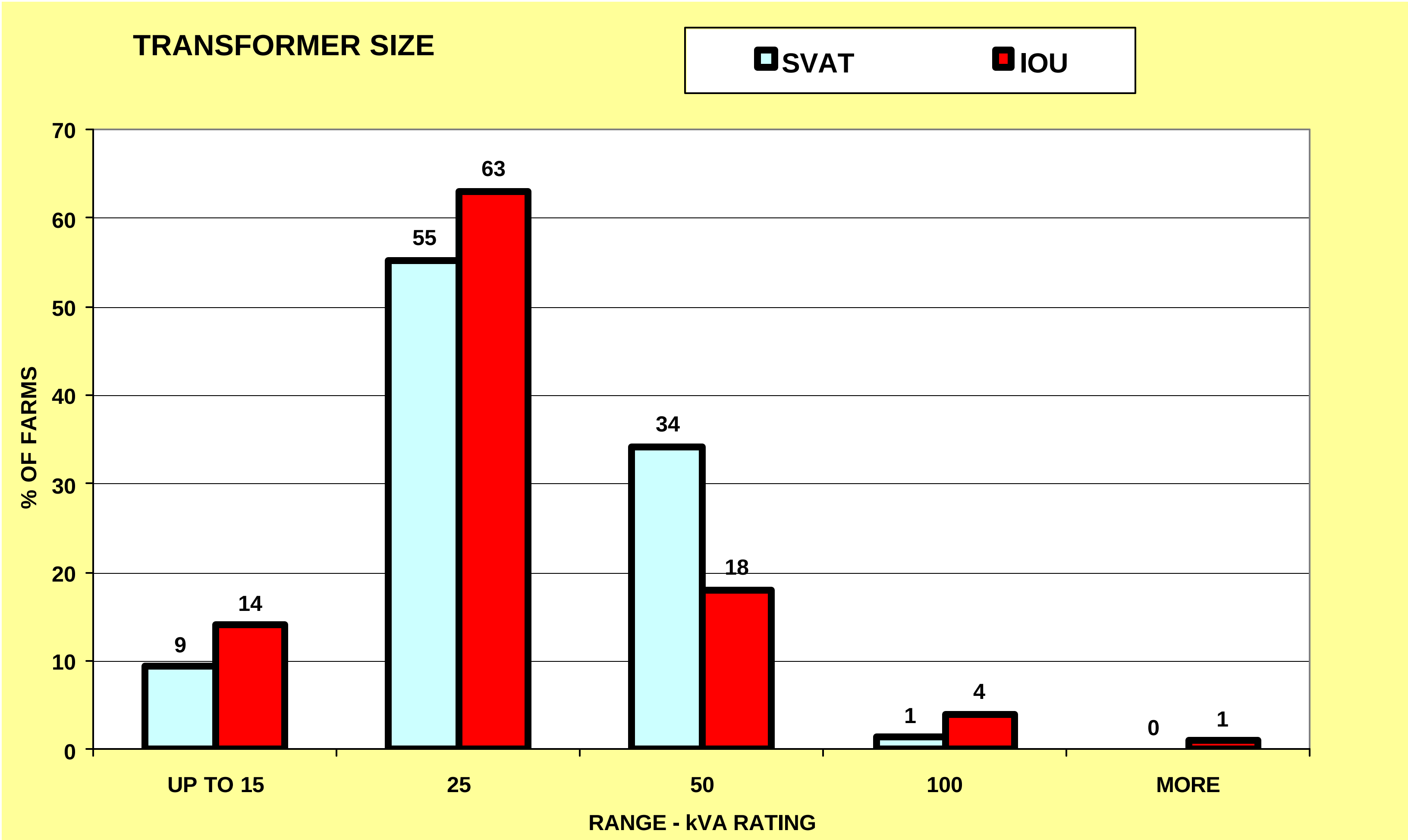

TRANSFORMER SIZE
SVAT
IOU
70
60
50
40
30
20
10
0
% OF FARMS
9
14
55
63
34
18
1
4
0
1
UP TO 15
25
50
100
MORE
RANGE - kVA RATING

FIGURE 4

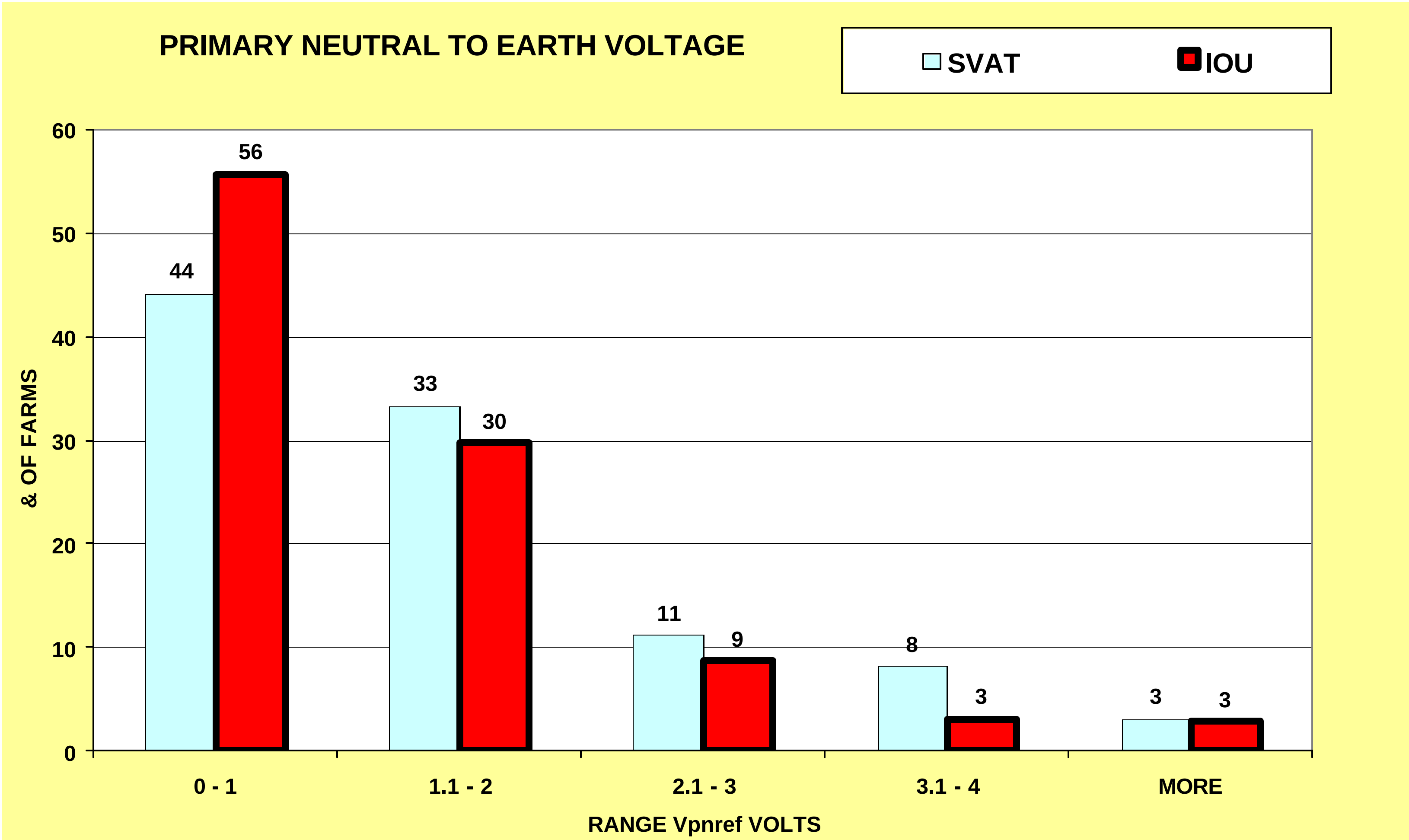

PRIMARY NEUTRAL TO EARTH VOLTAGE
SVAT
IOU
60
50
40
30
20
10
0
& OF FARMS
56
44
33
30
11
9
8
3
3
3
0 - 1
1.1 - 2
2.1 - 3
3.1 - 4
MORE
RANGE Vpnref VOLTS

FIGURE 5

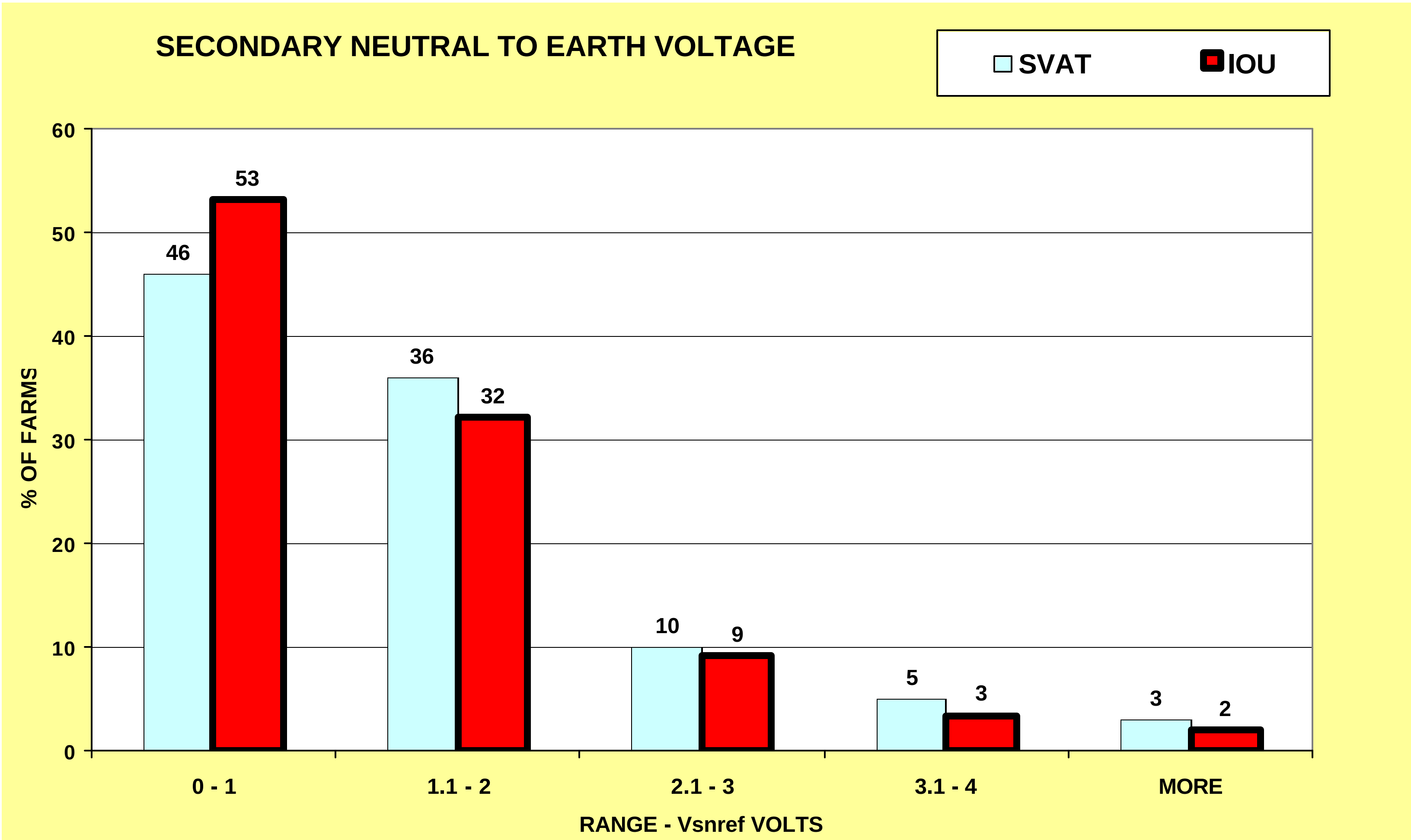

SECONDARY NEUTRAL TO EARTH VOLTAGE
SVAT
IOU
% OF FARMS
0
10
20
30
40
50
60
46
53
36
32
10
9
5
3
3
2
0 - 1
1.1 - 2
2.1 - 3
3.1 - 4
MORE
RANGE - Vsnref VOLTS

FIGURE 6

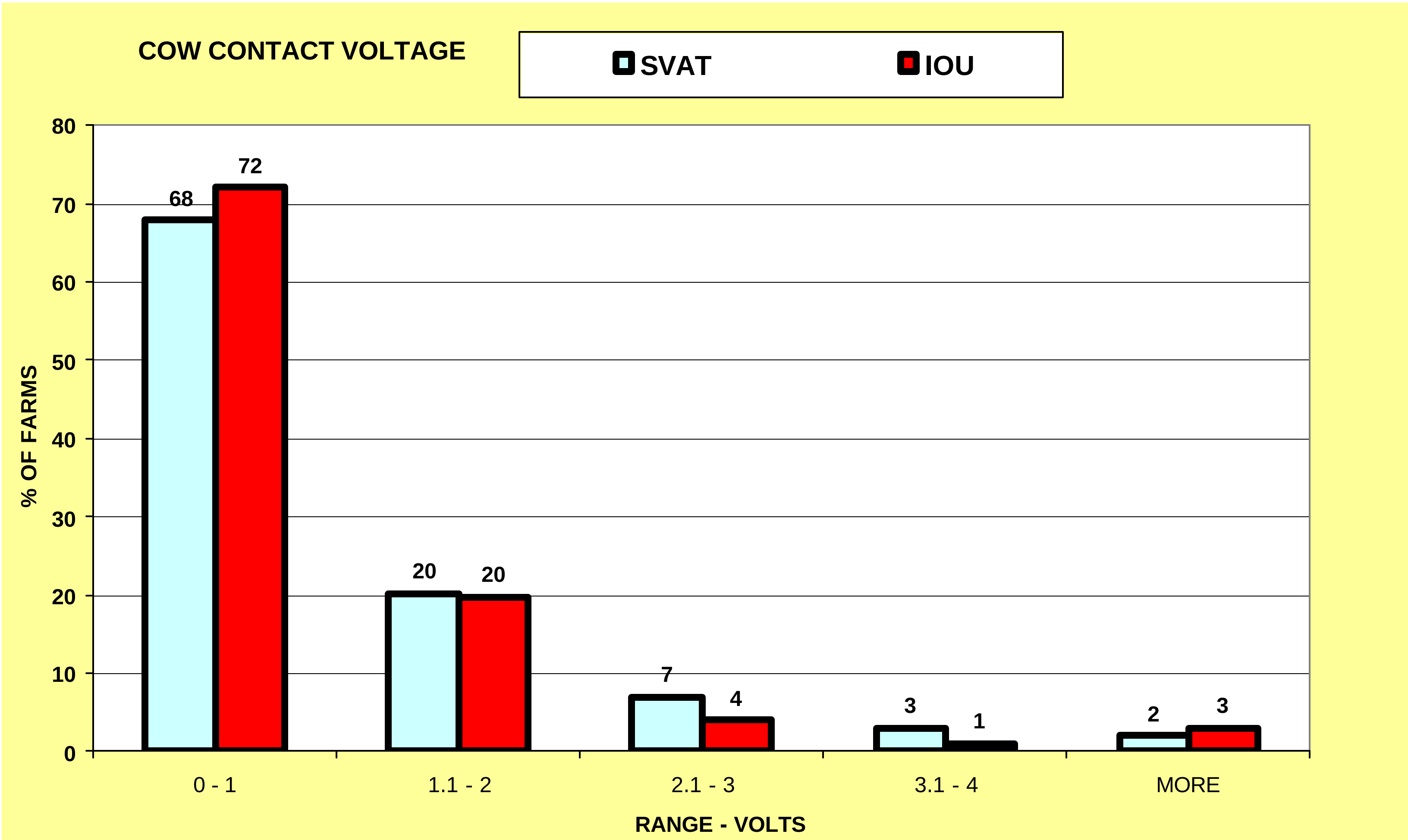

COW CONTACT VOLTAGE
SVAT
IOU
80
70
60
50
40
30
20
10
0
% OF FARMS
68
72
20
20
7
4
3
1
2
3
0 - 1
1.1 - 2
2.1 - 3
3.1 - 4
MORE
RANGE - VOLTS

FIGURE 7

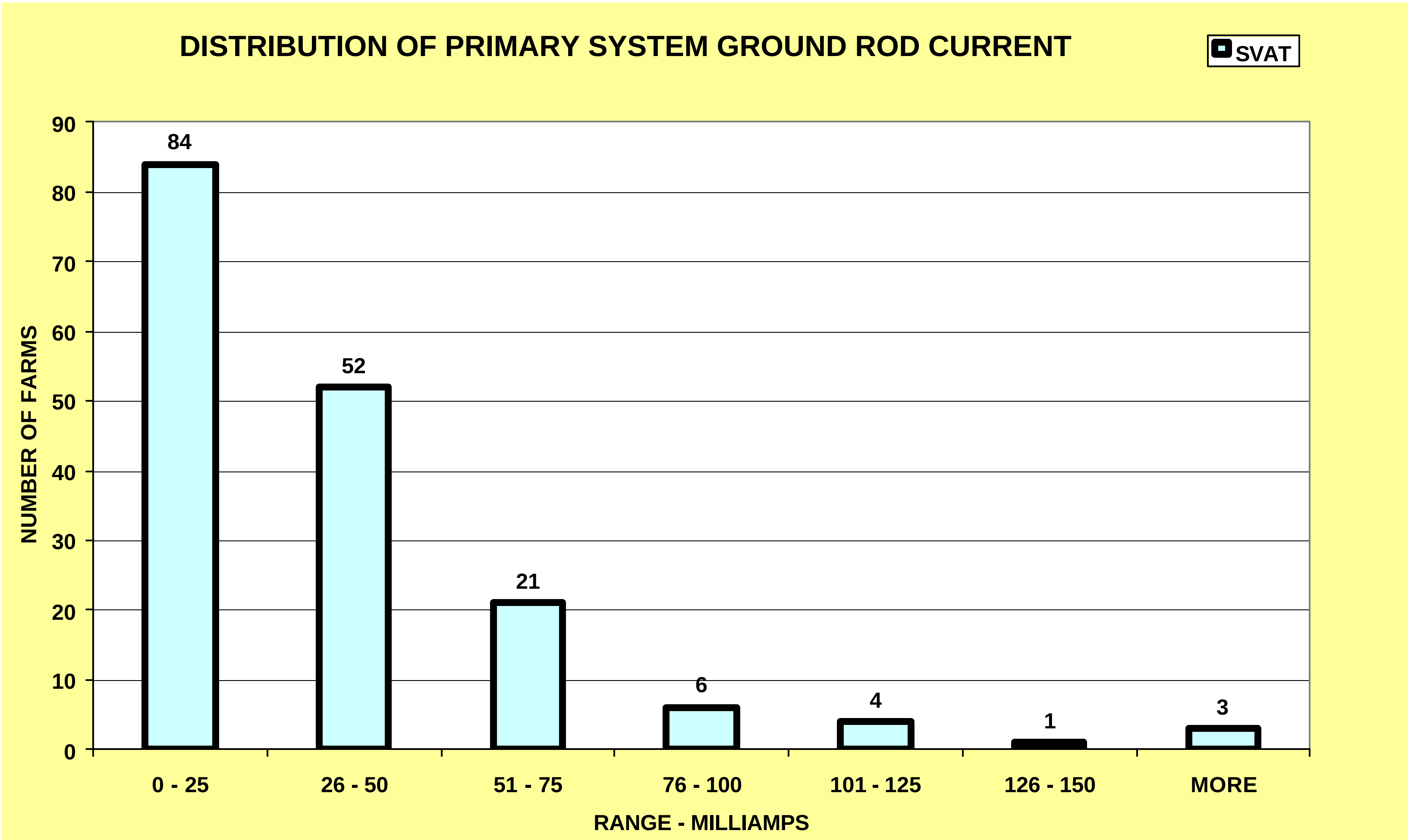
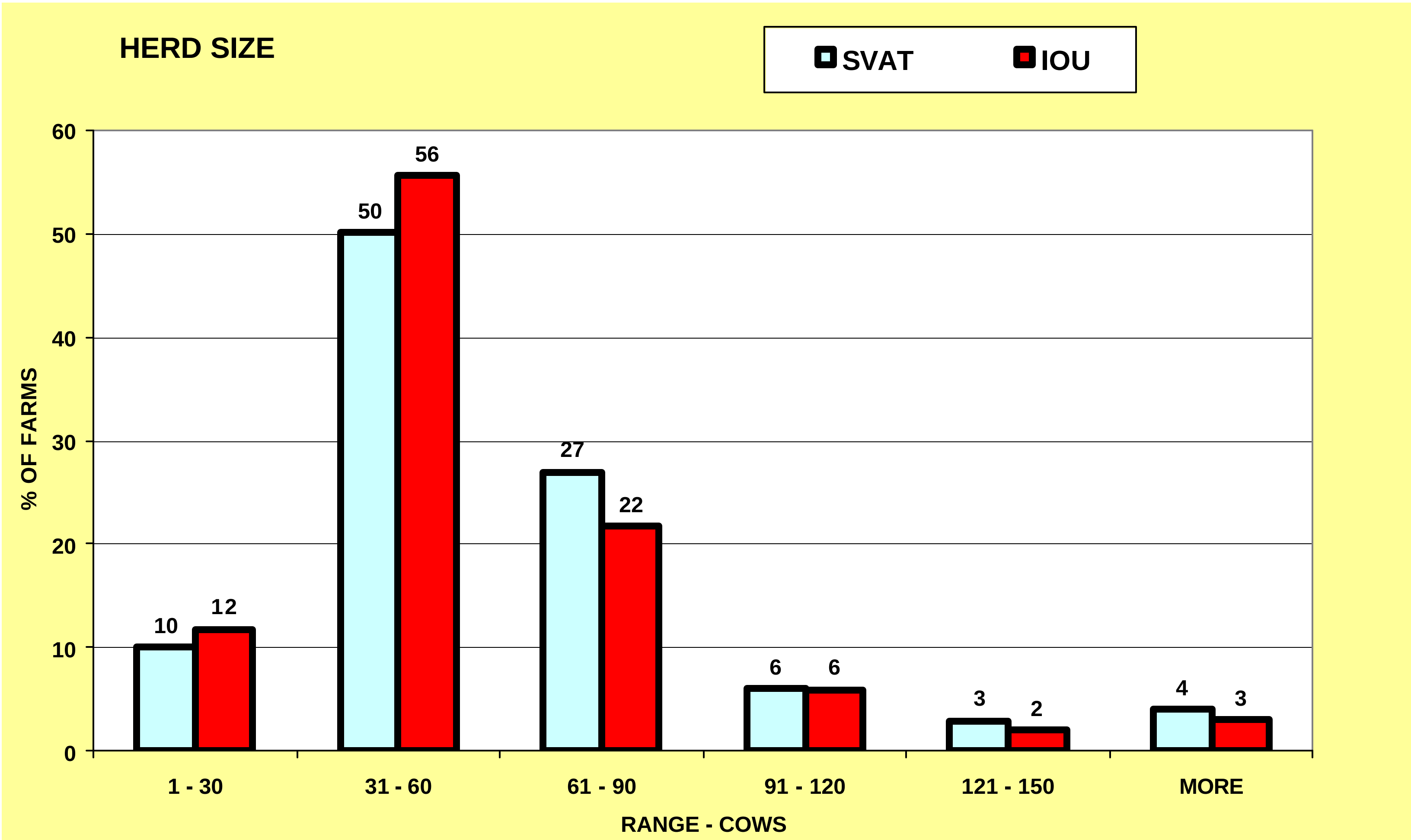
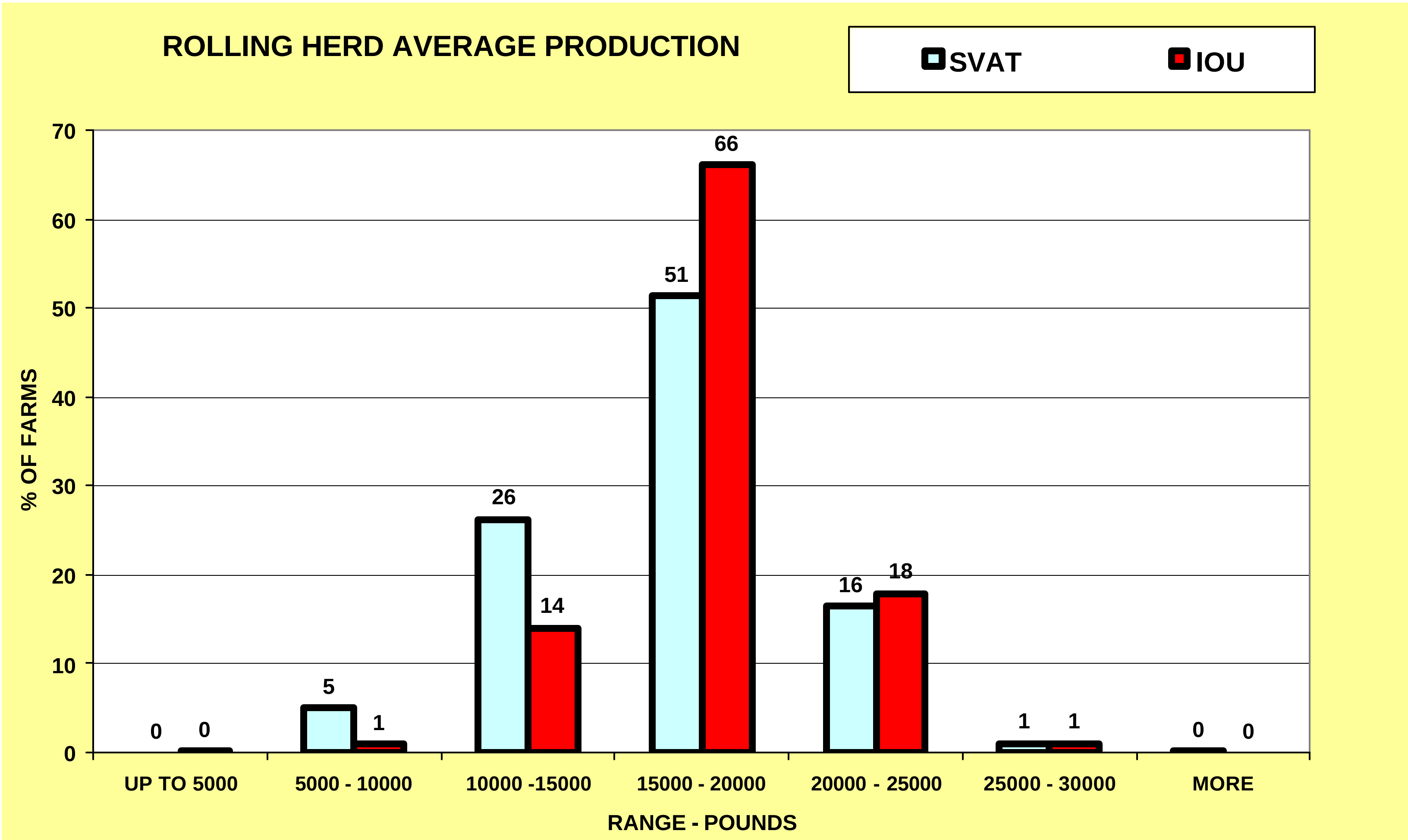

DISTRIBUTION OF PRIMARY SYSTEM GROUND ROD CURRENT
SVAT
NUMBER OF FARMS
0
10
20
30
40
50
60
70
80
90
84
52
21
6
4
1
3
0 - 25
26 - 50
51 - 75
76 - 100
101 - 125
126 - 150
MORE
RANGE - MILLIAMPS

FIGURE 8



HERD SIZE
SVAT
IOU
% OF FARMS
0
10
20
30
40
50
60
10
12
50
56
27
22
6
6
3
2
4
3
1 - 30
31 - 60
61 - 90
91 - 120
121 - 150
MORE
RANGE - COWS

FIGURE 9



ROLLING HERD AVERAGE PRODUCTION
SVAT
IOU
% OF FARMS
70
60
50
40
30
20
10
0
0
0
5
1
26
14
51
66
16
18
1
1
0
0
UP TO 5000
5000 - 10000
10000 -15000
15000 - 20000
20000 - 25000
25000 - 30000
MORE
RANGE - POUNDS

FIGURE 10

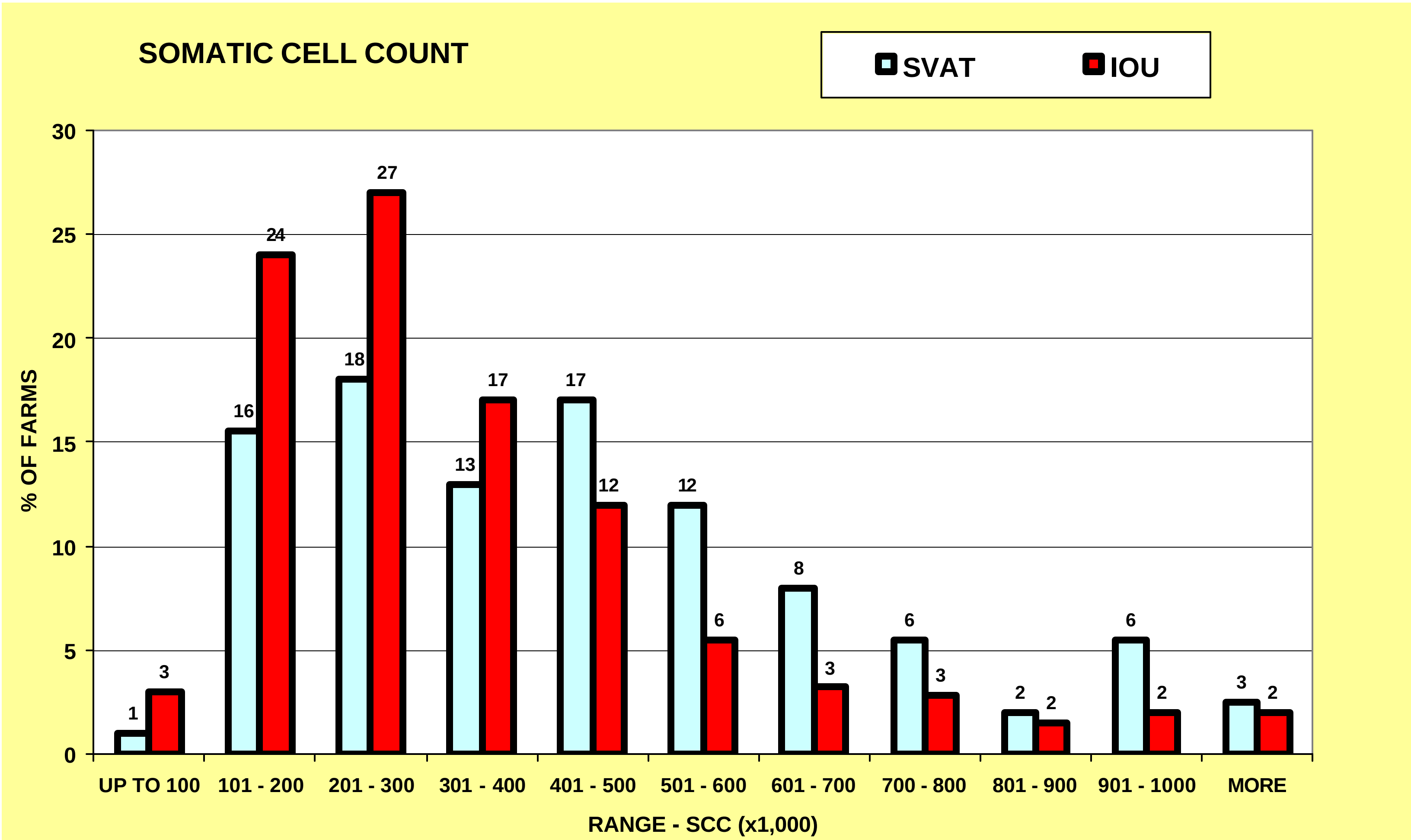

SOMATIC CELL COUNT
SVAT
IOU
% OF FARMS
0
5
10
15
20
25
30
1
3
16
24
18
27
13
17
17
12
12
6
8
3
6
3
2
2
6
2
3
2
UP TO 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
700 - 800
801 - 900
901 - 1000
MORE
RANGE - SCC (x1,000)

FIGURE 11

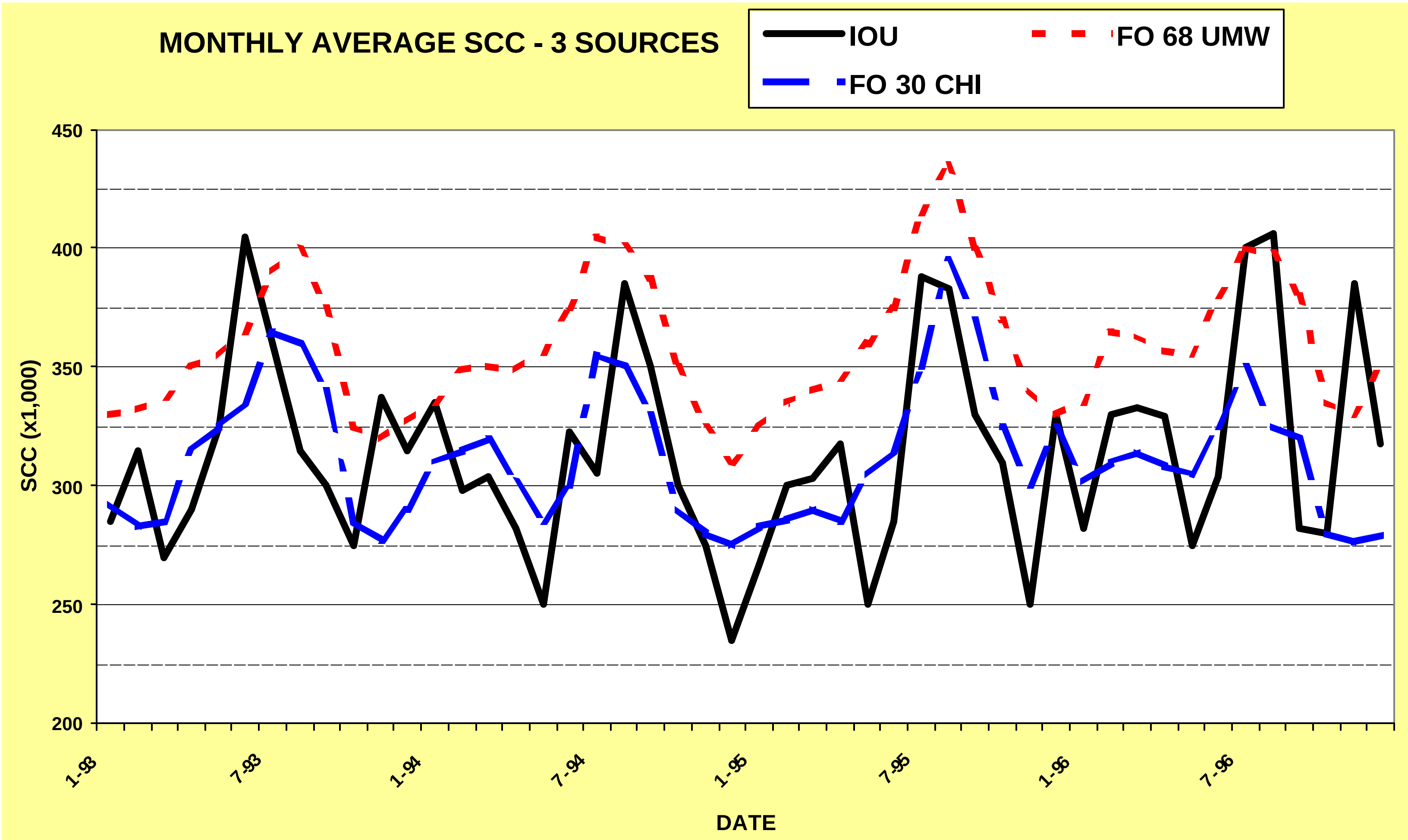

MONTHLY AVERAGE SCC - 3 SOURCES
IOU
FO 68 UMW
FO 30 CHI
450
400
350
300
250
200
SCC (x1,000)
1-93
7-93
1-94
7-94
1-95
7-95
1-96
7-96
DATE

FIGURE 12